

Adversarial collaboration decision-making: An overview of social quantum information processing

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Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2002		2. REPORT TYPE		3. DATES COVERED 00-00-2002 to 00-00-2002	
4. TITLE AND SUBTITLE Adversarial collaboration decision-making: An overview of social quantum information processing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Paine College,Math and Psychology Departments,1235 15th Street,Augusta,GA,30901-3182				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES 2002 Command and Control Research and Technology Symposium					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 11	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Abstract

While believing that cooperation is the most efficient form of social behavior (e.g., Nowak et al., 2000), collaborative decision-making (CDM) to solve problems is an aspect of human behavior least yielding to rational predictions. To reduce the complexity of CDM, early game theorists assumed that cooperation and conflict could be represented by static configurations of the choices confronted by humans in a “game” interaction, leading to the first stable solution of mutual competition (Nash equilibrium), followed by the evolution in repeated games of a second stable solution of mutual cooperation (Axelrod, 1984). But logic underdetermines reality, *R*; cooperation in the field to solve ill-defined problems produces suboptimal solutions; and a rigorous logical map from multiple individual preferences to a single group preference is not possible (Arrow, 1951). More problematic for multiple agent systems or computational autonomy, as information (*I*) uncertainty is reduced to produce knowledge (*K*), as the number of interactants approach an *N* of 100 or more, or, ironically, as the number of agents participating in cooperative behavior increases, computability decreases significantly. In contrast, adapting quantum logic to adversarial collaboration produces a robust model of decision-making even as *N* increases. Implications for C2 decision-making are discussed.

Overview of research

Game theory was one of the first rational approaches to the study of the interaction (Von Neumann & Morgenstern, 1953). Some of the strengths and weaknesses of game theory are listed in Table 1. While game theory is emblematic of rational theories of the interaction, its weaknesses preclude it from being predictive. Of greater concern, it is unable to study the weaknesses and strengths of cooperation as a variable, the shift from individuals to groups, or variations between groups.

Past research indicates that cooperation works best for well-defined problems (Lawless et al., 2000b), but game theory is not able to study when cooperation does not work, such as innovation (Lawless et al., 2000a), social loafing (Latane, 1981); asymmetric *I* (e.g., deception like the 9/11 attack on the World Trade Center); or corruption (e.g., Enron’s \$20 billion loss; Japan’s inability to reform; Germany’s fall from 14th in 1999 to 20th in 2000 on the Transparency International corruption index). Research into cooperation indicates that it can be problematic at group or national levels (Lawless & Castelao, 2001). For example, the European Commission recently concluded that “The requirement for consensus in the European Council often holds policy-making hostage to national interests in areas which Council should decide by a qualified majority” (WP, 2001, p. 29). Further, game theory is unable to study quantitatively the organizational value of conflict or violence (Cohen, 2002), whether conflict is derived from anarchy, state sanctions, or state sponsors (Wendt, 1999).

The weaknesses of game theory permit alternative approaches to study the interaction, both in quantum information processing (QIP). One QIP alternative is Quantum Game Theory (Arfi, under review), which has the strength of combining cooperation and competition, or the entanglement between incommensurable groups, but it lacks field support. Another is the Social Quantum Information Processing (S-QIP) model, which overcomes many of the weaknesses of game theory and has field support (e.g., Lawless, 2001). Theoretical justification for S-QIP is that it models the two mutually exclusive roles of action and observation that constitute all

interactions between organisms (Bohr, 1955), which parallels the cognitive organization of the human brain into an “on-line” system outside of awareness for motor operations on the environment, and a situational awareness system jointly organized from the bottom up by sensory input and the top down for planning (Crick & Koch, 1998).

Table 1: Strengths and weaknesses of game theory.

Strengths	Weaknesses
Rational model of the interaction (event trees, conditional probabilities)	Emotion is not integral to the model
Mathematical logic of interdependence	Uncertainty is modeled sequentially, not interdependently (i.e., uncertainty in observation is followed by uncertainty in action)
Mixed motives of conflict and cooperation	Argumentation, incommensurability, and diversity have zero social value (Nash, 1950)
Mathematical equilibria (e.g., Nash; Axelrod)	Static configurations and equilibria force information processing (dI/dt) to occur “extra-rationally” (i.e., reactive to observations of other’s behaviors)
Quantitative utility of expected outcomes	Arbitrary utilities for cooperation and competition lead to explanation versus prediction, overstating the value of cooperation (e.g., Shearer & Gould, 1999; Axelrod, 1984)
Models lead to clear predictions	No validation in lab (Kelley, 1992) or field (Jones, 1998)
First models of group behavior	Shifts between individual to group utility or ingroup to outgroup utilities cannot be studied
Generalizable	Conclusions are normative (Gmytrasiewicz, 2002)

There are other reasons for S-QIP. Due to recoding between multiple stages in the brain, "it is inherently impossible to communicate [with words] the exact nature of what we are conscious of " (Crick & Koch, 1998). But even if concepts precisely corresponded to objects in the environment (Einstein et al., 1935), which they do not (Zeilinger, 1999), "the firing of many cortical cells does not correspond to what the animal is currently seeing" (Crick & Koch, 1998). For example, blindsight patients can follow a light source yet deny "seeing" it. As Zeilinger explains, ending entanglement at the quantum level leads to individual histories which cannot be recombined to reconstruct entanglement.

Luce (1997) has used the quantum theory to account mathematically for ROC curves (probability of hits and false alarms). Subjects are aware of short duration stimulations between 0.2-0.5 ms (Crick & Koch, 1998), but respond to stimulation of even shorter durations outside of awareness, such as emotional responses (Zajonc, 1998). Eyeblinks (30-50 ms) and saccades scarcely interrupt visual perceptions. Mitochondria produce packages (quanta) of energy for the use by cells (7.3 kCal/mol). Frohlich (1983) has conjectured that collective vibrational modes

(coherent phonons) in biological membranes act as a Bose-Einstein condensate, an ordered cooperative state in which vibrational E is in its lowest mode. Hameroff (1998) and Penrose (1994) have proposed that QIP constructs the high-energy gamma waves now believed to form consciousness or awareness (40 Hz implies 25 ms per oscillation). And movies and television are rapidly presented static images (from around 100 ms in early movies to about 15 ms with current tv imaging) that give the illusion of action.

The S-QIP model is also relevant because oscillations occur in the brain continuously (Basar et al., 2001), producing patterns of superposition to indicate object presence and action certainty (Zlot et al., 2001), or interference to indicate uncertainty and the inability to act (e.g., “diffusion of responsibility”, in Latane, 1981), giving organisms the ability to “tune” or “engage” aspects of their environment, such as the cocktail party phenomenon (Clark, 1996), suggesting that organisms can control and be controlled with feedback in principle similar to interferometers as they seek richer I environments (Davis, 2001).

By storing I in the wavefunction of entangled particles, so long as coherence is maintained, a transformed wavefunction can simultaneously process exponentially more information than corresponding classical systems (Davis, 2001), the computation improving as a function of N (Preskill, 2000). Possibly, if local control is an attempt by individuals to form coalitions characterized by speech agreement (superposition) in order to better defend themselves (Rosenblatt et al., 1990), social control occurs when society “tunes” interactions between coalitions to maximize the incommensurability between them (interference) to process the optimal amount of I into K (Lawless & Castelao, 2001).

Learning in the social learning theory model (classical conditioning, operant conditioning, and modeling) occurs outside of awareness, indicating that it may be the primary means of learning for the online system; supporting this speculation, “free will” is considered superfluous to conditioning (Skinner, 1971), and an awareness of conditioning contingencies often leads to reactance (Brehm, 1966). But game theory models are based artificially on an individual “awareness” of contingencies in the interaction (Luce & Raiffa, 1967), implying perfect information, a weakness game theory has not overcome; in contrast, S-QIP as a non-linear model of the interaction requires an awareness of social differences (e.g., dissonance, transformational learning; law; science; economics; etc.).

Coming from a game theory perspective, cooperation produces the fairest, most efficient, and most just society (e.g., Nowak et al., 2000). In this perspective, disagreement and competition lead to less trust (e.g., Shearer & Gould, 1999; Worchel, 1999). The embodiment of this perspective is the command economy (e.g., dictatorship; Hitler’s Germany), which works when problems are well-defined. However, S-QIP predicts oppositely that cooperation inside of groups and disagreement and conflict between ingroups and outgroups are required for society to optimally solve ill-defined problems, the hallmark of democracy. As Justice Scalia has remarked, violence is the price of a free society.

Other benefits of S-QIP include: Emotion is integral to the theory (Lawless, 2001); it has modeled the social responses to catastrophes and business mergers in response to falling prices (Lawless & Castelao, 2001); it combines social learning theory and dissonance theory (cooperation employs K , but competition is required to generate I and convert it to K); and it has support from lab to field (Lawless, 2002b). Its drawbacks include: Human meaning arises from convergence process, implying that incommensurability is difficult to model or to understand (Campbell, 1996).

Theory

Based on the social quantum relations (Lawless et al., 2000a), action information uncertainty, Δa , and observation information uncertainty, ΔI (where $I = -\sum p(x) \log_2 p(x)$), are conjugate:

$$\Delta a \Delta I \approx c \quad (1)$$

Two conclusions follow from Equation (1). First, since the constant c is unknown, the equation must be solved with boundary conditions (Lawless et al., 2000b). Second, Equation (1) indicates that action and observation uncertainty are interdependent and conjugate; interdependent by being mutually dependent, and conjugate because as one uncertainty is reduced to zero, the other becomes unbounded or hidden from view.

Boundary Condition 1 (as $\Delta I \rightarrow 0$, $\Delta a \rightarrow \infty$)

Air combat educators with the USAF had wanted to establish that education helped to make better fighter pilots. Based on Simon's (1992) prediction, they had expected that as information uncertainty about air combat went to zero, knowledge was gained ($\Delta I \rightarrow 0 \Rightarrow K$) that could be taught to pilots and then used to predict winning outcomes. Their prediction was tested with 125 USAF combat pilots in eight 3-min air combat maneuvering encounters against machines and human. K of air combat was measured by a multiple-choice exam strongly weighted in favor of combat experience. Experience was the history of total flight-time combined with air combat field training (e.g., Red Flag). Multiple regressions indicated that experience predicted air combat wins, total aircraft E availability relative to opponents (i.e., a height or speed advantage over opponent), and an expert opponent's rating of fighter pilot performance. However, K did not predict wins-losses, E availability, or expert ratings (Table 2).

Table 2. USAF educators had predicted that K would predict who won or lost in air combat. Instead, the results indicated that K had no power to predict outcomes (from Lawless et al., 2000a).

Predictor	Prediction	Regression	Significance
Flight Experience (e.g., training)	Wins	0.34	.03
Relative Energy Available (compared to opponent)	Wins	0.37	.01
Rating by Expert Opponent	Wins	0.47	.0001
Multiple Choice Examination	Wins	0.00	n.s.
Multiple Choice Examination	Relative E	0.00	n.s.
Multiple Choice Examination	Rating by expert opponent pilot	0.00	n.s.

Boundary Condition 2 (as $\Delta a \rightarrow 0$, $\Delta I \rightarrow \infty$)

Equation (1) can also be used to help groups reach optimum decisions. Counterintuitively, Equation (1) predicts that uncertainty in observational information must increase to solve ill-defined problems. Typical examples are the practice of science at the cutting edge when pro-con positions are posed before neutral scientists, when the law in the courtroom is argued by prosecutors and defense lawyers before neutral jurists, and when disagreement arises during CDM.

In 1996, the Department of Energy (DOE) collected environmental remediation (ER) and waste management decision-making data from Citizen Advisory Boards (CAB) across its military nuclear weapons complex in the U.S., including the Savannah River Site in South Carolina (SAB) and Hanford in Washington (HAB), the two sites with the largest ER and waste management cleanup budgets (about \$1b in 1996). SAB used majority rule to make its decisions, and HAB used consensus rules. Today, having vitrified over 1200 canisters of nuclear weapons reprocessing wastes and having closed two of its 51 reprocessing waste storage tanks, SRS is the leader across the DOE complex (Lawless et al., 2000b). By comparison, Hanford has completed none in either category. Contrasting decision-making on both boards, SAB is significantly more adversarial in its decision making process ($\Delta I \rightarrow \infty$), yet its members trust each other more (see Table 3).

Table 3: t-tests between SAB (majority rule) and HAB (consensus rule) for demographics; survey items on perceptions of respective DOE sites; and survey items on internal decision processes (two asterisks for probability significance $p < .01$, one asterisk for probability significance $p < .05$; and no asterisks for not significant). The results indicate that at the group level, competitive decisions are superior to cooperative decisions (Lawless et al., 2000a).

Demographics	More Minority members	2.9 **
Relationship with DOE Site	Site heeds advice	4.7 **
	Concurs with Site	5.3 **
	Site progressing	1.6
	Trusts Site	1.6
Relationship with Members	Respects other members	-2.1 **
	Likes consensuses	-3.3 **
	Trusts other members	0.6
	Members share ideas	3.2 **

What was shown in Table 3 is that adversarial decision making works at the group level. The next study considered the effect of collaborative decision-making (CDM) versus adversarial decision-making again at the group level, but this time against a sophisticated numerical model. The Federal Aviation Agency has implemented CDM to improve convective weather forecasts (e.g., thunderstorms, tornados, hail) for commercial aviation (Table 4). Using the NCWF forecast, experts working alone produced the best short-term convective forecasts, followed by CDM then numerical models. One reason why CDM was less efficacious than single expert forecasters is that effort is necessary to improve the facility of using automated forecasts (Helmreich, 2000). A second reason is that participants wanted to increase safety margins and passenger comfort. But a third reason is that virtually no disagreement occurred during CDM (a similar lack of disagreement was found in a study of CDM METOC forecasts in an exercise at

sea; in Lawless, 2002a). For example, the amount of internal conflict on the SAB was significantly greater than on HAB, yet it produced superior decisions.

Table 4. In this table, better forecasts have a lower convective area covered by the forecast, a greater PODy, a lower FAR, and a Bias closer to one (bias greater than one over-predicts convection; less than one under-predicts). [SIGMET is significant meteorological information; NCWF is the automated computer generated numerical prediction; POD-y is the probability of a forecast being observed = $Y(\text{forecast})Y(\text{observed})/(YY+NY)$; FAR is the false alarm ratio = $YN/(YY+YN)$; and Bias is the tendency to over or under predict convection = $(YY+YN)/(YY+NY)$] (from Lawless, 2002a).

Product	Issued (UTC)	Forecast Length	Human/Automated	Average % area covered by Forecast	Average PODy	FAR	Bias
CCFP (CDM)	1500, 1900	1,3,5 and 3,5,7 h	H	5.2%	.28	.84	1.9
Expert SIGMET	Hourly	1,2 and 0-2 h	H	2.3%	.28	.70	1.0
Expert Outlook	Hourly	2-6 h and 6 h	H	14.9%	.04	.92	6.1
NCWF	5 min	1 and 2 h	A	0.5%	.09	.41	.10

Equation (1) can be revised to an equation based on time uncertainty, Δt , and energy uncertainty, ΔE (Lawless et al., 2000b):

$$\Delta t \Delta E \approx c \quad (2)$$

Equation (2) predicts that to reduce time uncertainty during the production of scientific K or technology (i.e. $\Delta I \rightarrow 0 \Rightarrow K$), to improve physical health, or to determine a defendant's guilt in the courtroom in an important case, E uncertainty becomes unbounded.

Boundary Condition 3 (as $\Delta t \rightarrow 0$, $\Delta E \rightarrow \infty$)

From a theoretical perspective, I to observers external to an interaction increases under competition and decreases under cooperation (Lawless et al., 2000b). With K as the absence of uncertainty ($\Delta I \rightarrow 0$), cooperation uses K to reduce E to best solve well-defined problems (social stability); in contrast, competition generates new K for the best solution of ill-defined problems, but E increases to do so (i.e., creative destruction; from Shumpeter, 1989). The results from a study of 15 nations (the nations were selected by May, 1997, for his study of graduate education) indicate that the more economic freedom and competition permitted and the more E available, the more scientific wealth (SW), technology (i.e., personal computers, PC's; and web use) and the better physical health (H) that accrued (Table 5). In contrast, unrestrained cooperation is associated with social loafing, asymmetric I (e.g., spying, terrorism, command economies, monopolies), and corruption. These results indicate that a system becomes more vulnerable when it is forced to become more cooperative until it becomes saturated (e.g., engaging a ship's fire control simultaneously with multiple targets from multiple directions until weapons are fired,

then retreating outside of weapon range, and iterate until overloaded). (For Boundary Condition 4, as $\Delta E \rightarrow 0$, $\Delta t \rightarrow \infty$, producing resonance, see Lawless & Castelao, 2001.)

Table 5. Correlation matrix for 15 nations between more Scientific Wealth (SW), poorer Health (H), more Energy expenditure, E , more personal computers per 1,000 capita (pc's), more internet web hosts per 10,000 capita (web), more Economic Freedom (EF), and less corruption (Corruption Perceptions Index, or CPI) (two asterisks imply $p < .01$; one asterisk implies $p < .05$; no asterisk implies not significant) (from Lawless & Castelao, 2001).

	1	2	3	4	5	6	7
1. SW	1						
2. H	-.72**	1					
3. E	.73**	-.66**	1				
4. pc's	.93**	-.70**	.78**	1			
5. web	.61*	-.37	.74**	.71**	1		
6. EF	.88**	-.79**	.70**	.84**	.48	1	
7. CPI	.81**	-.72**	.73**	.89**	.60*	.82**	1

Future research

The difficulty with human research is that surveys give only static information. Social influence occurs outside of the individual rational perspective tapped by surveys (Lawless, 2001). In an attempt to build on a rational, social quantum model of emotion, we compared paired repetitions of nine short neutral phrases from one subject speaking in a regular and angry voice (phrases similar to "beat about the bush"). Pitch frequencies were consistent for either normal or angry voice (the average for normal voice was 127 Hz, with SD 5 Hz; for angry voice 208 Hz, with SD 9 Hz). Speech samples were analyzed 100 at a time in sequence. After segmenting each pitch cycle for spectral analyses, one overall spectral pattern for each uttered phrase was generated. Results indicated a peak spectrum located in the low frequency region for normal voice but angry speech did not have a peak spectrum in the low frequency region. Pitch on average increased significantly for angry compared to normal voice ($t(8) = 24.8$, $p < .000$). CDM research with more subjects will be conducted.

Summary.

The game theory model of the interaction has provided a test bed for military maneuvers, including nuclear war and terrorism (e.g., Woo, 2002). One of the benefits of game theory is that it allows an event tree with conditional probabilities to be constructed to follow the planning steps in a military engagement, or the steps that a terrorist might follow to attack a target. However, the probabilities for each of these steps must be estimated by experts, rendering a value little different from expert planning. Further, the game theory model is static, offers no predictions that have been validated, and overstates the value of cooperation. Simply put, game theory produces normative results (Gmytrasiewicz, 2002). In contrast, while more difficult to understand, S-QIP is based on theory, and has biological, mathematical (e.g., Luce, 1997) and field support. S-QIP avoids many of the problems of game theory. It has important implications

for C2. It brings physics to a study of the social interaction, without discarding social evidence. And while difficult to understand, because meaning is a convergent, one-sided history of reality that undermines an appreciation of S-QIP, it is a step forward to a realistic model of the interaction, to study the problems that exist with cooperation, and to a study of the differences between groups.

Acknowledgements.

The author thanks J.A. Ballas and G. Kang, ITD, NRL, Washington, DC, where most of this research was conducted with funds from ONR through an ASEE grant.

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